

Chapter 3

Shoreline Change and Associated Beach Ridge Chenier Formations in the Subarnarekha Delta Region, India



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3.1 Introduction

The terrestrial sediments are downdrifted by the Subarnarekha River into the shallow sea region and redistributed along the shore by the marine agents of waves, tides, currents, and storm surges. In the time period between 7000 and 50 YBP, a series of Chenier sand ridges developed in front of stable shore positions (Paul, 1996a, b, 1997, 2002; Maiti, 2013; Kamila et al., 2021). In the initial phase of sand ridge formation, the coarser sands and marine shell fragments were deposited in the shallow mudflats by the strong storm surge from the shallow sea region to form the beach ridge (Jana & Paul, 2019; Sebastian et al., 2019). The shape, size, and extension of the respective sand ridges coexist with the direction of the longshore drift associated with the dominance of monsoon winds (southwestern and northeastern monsoons) (Kunte & Wagle, 2005; Kaliraj et al., 2014). The volume of terrestrial sediment supply into the shallow sea region is associated with the strengthening and weakening of the monsoon through the actions of weathering and erosion in the entire basin area (Banerji et al., 2020; Mandal et al., 2021). The repeated nature of sea level indicates the inter-dune spacing across the delta region (Jana & Paul, 2022). In these concerns, the barrier bars have been formed in the shallow sea region, backed by the shallow mudflats dominated by the tidal environment in a stillstand phase of the sea level (Paul, 1996a, 2002; Jana & Paul, 2019; Kamila et al., 2021). In the regressive phase, the sea level retreats and the barrier bar forms in a further seaward position, and again the shallow mudflats form in backwater regions dominated by the tidal environment (Paul, 2002; Barman et al., 2016). The previously known barrier bars were transformed into dune ridges as a result of sediment supplied from the wide beach zone. As a result of the regressive phases of sea

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level, shallow mudflats emerged and transformed into swale landforms. The width of the swale landscape indicates the rate of sea level retreat during the respective regressive phases of sea level. The presence and absence of dune ridges and swales on both sides of the Subarnarekha river indicate the strength of longshore drift, reflected in the strength of the northeastern or southwestern monsoon, along with the volume of terrestrial sediment supply into the shallow sea region.

Till now, lots of work has been done in this region regarding the landscape setup, geomorphology, and mechanism of chenier formations (Maiti, 2013; Jana et al., 2014; Jana & Paul, 2018, 2019, 2020, 2022; Kamila et al., 2021). The majority of these studies, however, have been conducted on the delta's eastern side, leaving the western side largely unexplored, despite being mentioned in a few works (Niyogi, 1968; Paul, 1996a, 2002). Although the actual mechanism of chenier formations cannot be explained properly without the study of the entire delta region in one work, there are lots of diversities in landscape and geomorphology on both sides of the delta region. Therefore, this study has been carried out over the entire Subarnarekha delta region on the aspects of landscape, geomorphology, and beach ridge-chenier formations in association with the concomitant nature of shoreline positions.

3.2 Material and Methods

3.2.1 Study Area

The study has been carried out in the deltaplain region on both sides of the Subarnarekha River course, which extends from the Rasulpur river in the east to the Budhabalanga river in the west, covering parts of the states of West Bengal and Odisha (Fig. 3.1). This study area is about 90 km long along the Bay of Bengal coastline and about 30 km wide in the interior part of the deltaplain. Although the present study has been done on the chenier mechanism of the Subarnarekha delta region, the study area has been selected far inland and extends beyond the chenier landforms to explain the process of delta formations as well as the mechanism of chenier formations over the deltaplain during the different time periods (Jana, 2017, 2021).

3.2.2 Database and Data Processing

In the study, the shuttle radar topography mission (SRTM) 1-arc second (30 m) resolution digital elevation model (DEM)-based data from 2015 was considered for terrain analysis and also to find out the different morphological features. The differential global positioning systems (DGPS) survey extracted elevation data from 1000 ground control points (GCPs) from various terrain units. The DGPS provides elevation data considering the earth as an ellipsoid surface, the World Geodetic System 1984 (WGS84), and the Earth Gravity Model (EGM96). Therefore, the

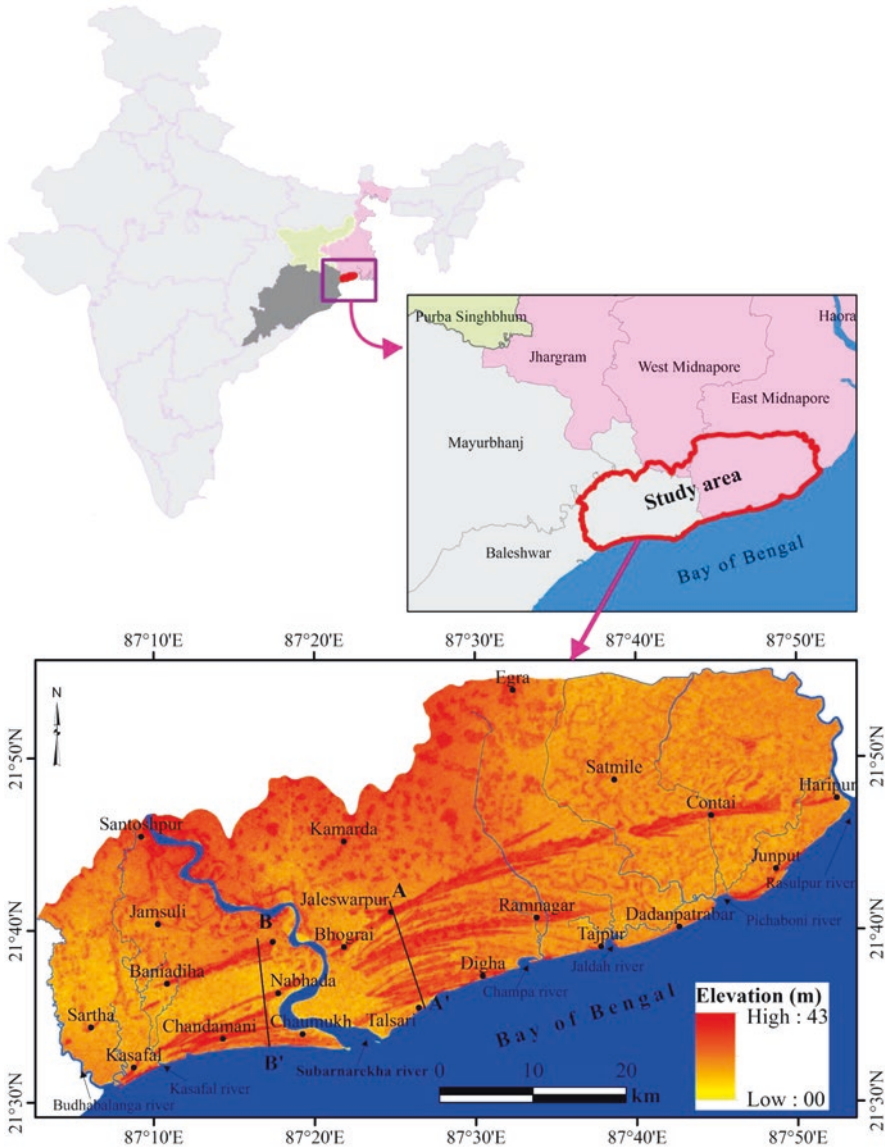


Fig. 3.1 The study area in the Subarnarekha delta plain, selected from the Rasulpur river in the east to Budhabalanga river in the west. The DEM shows the sequential pattern of dune ridges

collected DGPS data were converted into an equipotential geoidal surface corresponding to the mean sea level (MSL) as a local vertical datum (Pavlis et al., 2012; Patel et al., 2016). The SRTM image was resampled to 10 m spatial resolution after subpixel analysis (Mokarrama & Hojati, 2018). The vertical accuracy of the resampled SRTM data was validated with randomly taken 300 DGPS-based elevations, which divulge ± 0.12 m root mean square error (RMSE).

The landscape features of the Subarnarekha delta plain were extracted from the finally processed 10 m-resolution SRTM data. The differential elevations of the various landscape features were defined by the contour patterns. Moreover, the Google Earth image was also considered for accurate detection of the landscape features. In a similar way, the geomorphological diversities of the entire study area were extracted and finally processed into ArcGIS 10.1 software to get the final output. Also, the cross-profiles were extracted from the SRTM data.

3.3 Results and Discussion

3.3.1 *Landscape Evolution of the Subarnarekha Delta*

The delta head of the Subarnarekha delta plain exists near Keshiary, about 30 km north of the present study area. About 7000–6000 YBP, the eastern tectonic shelf zone of the Bengal Basin was subsided along the subsurface Damodar fault (DF) (Ghosh & Guchhait, 2015; Jana & Paul, 2018). Moreover, along the margin of the Medinipur-Farakka fault (MFF), a fault-line scarp has been formed due to tremendous erosional activities (Biswas, 1987). Simultaneously, a marine transgression event occurred on the current surface of the Subarnarekha delta plain. During the early Pleistocene, the entire ancient delta plain (between MFF and DF) subsided and came under the depositional environment of the marine aggradational process during highstands. Furthermore, the lateritic upland (between the Chotanagpur foothills and the MFF) was uplifted as a result of increased weathering activity for a prolonged arid climate and erosional activity, which was exacerbated by the strengthening of the monsoon in this region between 5800 and 4300 YBP (Biswas, 1993; Banerji et al., 2020; Jana & Paul, 2020). However, the shoreline was located at the margin of the ancient delta plain during 80,000 YBP, indicating that the entire study area was under pro-deltaic conditions influenced by brackish water and a marine environment until the early Pliocene (Mallick et al., 1972). After that, the sea level regressed and the depositional environment was shifted to a shallow marine, estuarine, and fluvial-dominated environment (Mallick et al., 1972). Therefore, the ancient fluvio-marine delta fan terrace was formed in the northern part of the study area (Fig. 3.2) by the sequential phases of marine and fluvial environments, followed by an ancient marine terrace formed by the dominance of marine environments in the delta plain (Niyogi, 1968; Paul, 1996a, b, 2002; Jana & Paul, 2019).

In the earlier period of 7000 YBP, the rivers Subarnarekha and Rasulpur were two distributaries that fell into the Bay of Bengal across the entire delta plain (Paul, 2002; Maiti, 2013; Kamila et al., 2021). Furthermore, the Pichaboni, Jaldah, and Champa rivers of the delta region were linked to the main stream of the Subarnarekha River. However, the distributaries of Subarnarekha and Rasulpur carried huge sediments from the upper catchment areas and deposited them over the delta plain along with sediment downdrift into the shallow sea region of the Bay of Bengal. During

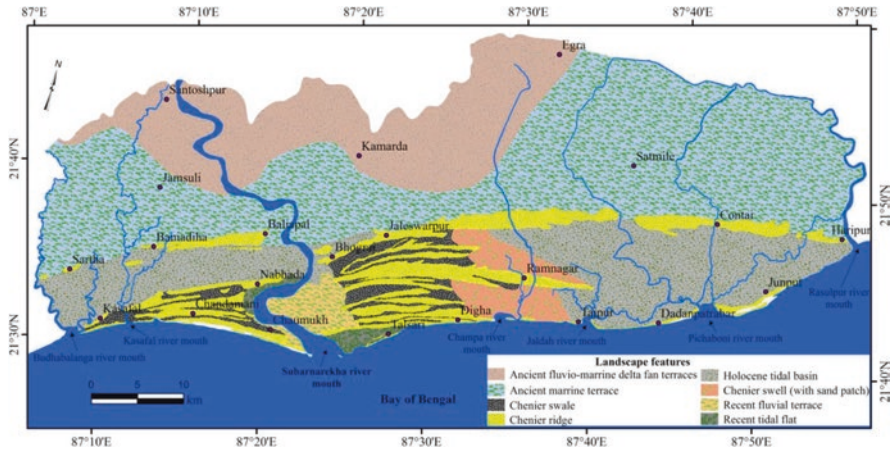


Fig. 3.2 Landscape features of the Subarnarekha delta plain

5000 YBP, the river Hugli drifted more sediment into the northern head of the Bay of Bengal, around the Rasulpur river mouth region, with stronger sedimentary environmental foci (Allison et al., 2003; Kamila et al., 2021). The finer mud particles were thrown farther westward with the dominance of the northeastern monsoon. During 7000 YBP, the Rasulpur river was beheaded from the main course of the Subarnarekha River (Paul, 2002; Maiti, 2013). The downdrift sediments into the shallow sea region of the Bay of Bengal were redistributed along the shoreline by the longshore drift to form the beach ridge, which was turned into a dune ridge (Contai – Baliapal dune ridge) (Fig. 3.2). Afterward, the Subarnarekha River became a single channel system and threw its finer sediment towards the west in the Baliapal region. Therefore, a wide and elongated tidal basin was formed in the front side of the elongated Contai–Baliapal dune ridge (first stage) during the Holocene period (Figs. 3.2 and 3.3).

The other dune ridges in the delta plain are not as long as the Contai–Baliapal dune ridge. During 5760–5000 YBP, the second and third stages of dune ridges (Figs. 3.2 and 3.3) were formed to a shorter extent in comparison to the Contai–Baliapal dune ridge. However, during 5800–4300 YBP, when the Indian summer monsoon was strengthened by nature (Banerji et al., 2020; Jana & Paul, 2020), the Subarnarekha River was the only channel that downdrifted sediments into the shallow sea region (the Rasulpur river had already been severed). As a result, the longshore current was unable to transport much sediment along the shoreline (Paul, 1996a). This situation is also applicable for the other conjugative stages (4th–9th) of the dune ridge formations in the delta plain (Fig. 3.3). The inter-dune chenier swales were formed as a result of the concomitant nature of sea level caused by the nature and temporal extents of stillstand and the aggressive and regressive nature of the sea levels. In general, dune ridges formed during stationary sea level positions. But at the reiterating phase of sea level, the drifted sediments did not get much time to settle in a suitable place to form dune ridges. Therefore, the chenier swales were

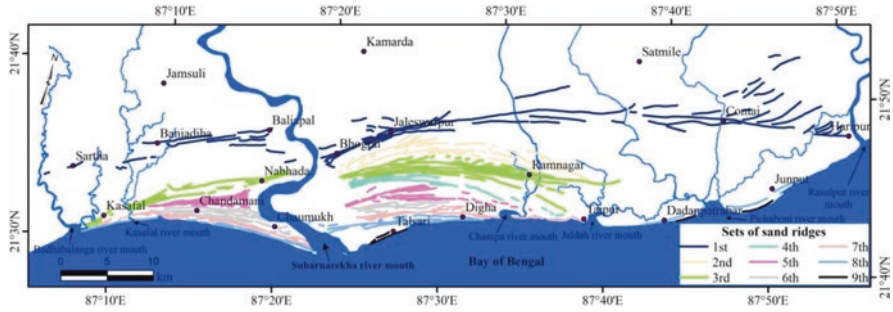


Fig. 3.3 Nine sets of dune ridges within the chenier landscape of the Subarnarekha delta plain

formed in between the dune ridges as marine terraces composed of silt and clay materials (Figs. 3.2 and 3.3). The chenier swales with sand patches (Fig. 3.2) formed in the far western extent of the Holocene tidal basin where finer mud from the Hugli system could not reach and finer sands from the Subarnarekha system were thrown east by longshore drift after settling of relatively coarse sands into the beach ridge and dune ridge surface.

The recent fluvial terrace of the Subarnarekha River system was formed after the westward shifting of the Subarnarekha River course just after the Bhograi section (Fig. 3.2). This shifting of the river course probably happened during the 2900 ± 160 YBP (Maiti, 2013) guided by the westerly littoral drift (Paul, 1996a; Niyogi, 1968). The fifth to seventh stages of dune ridges were formed during the same period (Maiti, 2013). Moreover, the dune ridges of the fifth stage extended more westward (on the right side of the Subarnarekha River) than the eastern extent of the dune ridge (Figs. 3.2 and 3.3). But the seaward bulge of the delta plain was more on the eastern side. This contradictory situation indicates that the southwestern monsoon was strong enough during this period (after a brief period of dominance by the northeastern monsoon) to drift the sediment towards the east, forcing the Subarnarekha course to turn again towards the east, and the sedimentary foci of the Subarnarekha river were also extended towards the east, causing more sediment to be thrown in the same direction. The recent tidal flat in the Talsari region was formed during the 200–50 YBP, as the dune ridge of the eighth stage was developed during the 200 YBP (Maiti, 2013), and the shorefront dune at Talsari was formed around 50 years ago (Paul, 2002). The marine sediment was deposited over the tidal flat dominated by the backwater marine environment between 200 and 50 YBP.

3.3.2 *Changing Pattern of Shorelines and Associated Marine Environment*

The seven sets of shoreline positions coexist with the geomorphic features of the beach ridges (Fig. 3.4). Beach ridges indicate shoreline positions because they are formed directly by the storm energy wave environment through the deposition of

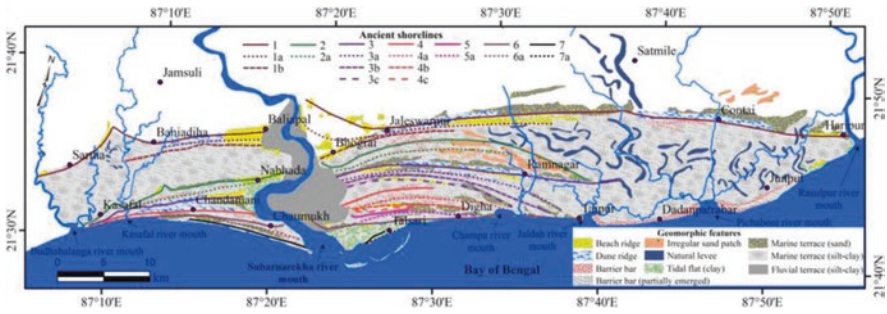


Fig. 3.4 Diversified geomorphological features of the Subarnarekha delta plain. (Modified after Niyogi, 1968)

coarser sands and shell fragments in appropriate shorefront areas (Paul, 1996a). Moreover, the barrier bars have also been formed with the effects of longshore drift regulated by the shoreline positions. Therefore, the beach ridge and barrier bar give a clear idea about the configurations of the ancient shorelines (Paul, 2002). The first phase of the shoreline (shoreline 1) and adjacent shorelines (shorelines 1a and 1b) indicate the RIA type of submergent shoreline (Niyogi, 1968) near the Subarnarekha River course (around Baliapal) and Kasafal river course (around Baniadiha and Sartha section) (Fig. 3.4). The configuration of the shorelines 1a and 1b appears to extend to a shorter extent adjacent to the beach ridges in front of the estuary and is absent away from the estuary. When compared to the earlier RIA type shoreline (Niyogi, 1968), these two shorelines (1a and 1b) indicate that the estuary valley was gradually filled up and straightened. The second phase of shorelines (shorelines 2 and 2a) remain closer to shoreline 1b on the delta plain’s eastern side but further away from the 1b shoreline on the western side, separated by the wide marine terrace (Fig. 3.4). The process of delta formation (delta extension) moved more quickly on the east side of the delta plain than on the west. Therefore, shoreline 3 exists on both sides of the delta region, and the other three conjugative shorelines (3a, 3b, and 3c) do not exist on the western side of the delta plain (Fig. 3.4). Similar conditions have been found for shorelines 4, 4a, 4b, and 4c. The 5 and 5a shorelines exist along the barrier bars in the eastern part of the delta plain, which are not found on the western side. This also shows the bulge of sediment on the delta plain’s eastern side, which is dominated by the backwater cum marine environment on the backside of the Digha dune (eighth phase). Very interestingly, shoreline 6a is only present in the western part of the delta plain along the configuration of barrier bars, which indicates the delta extension rate was higher on the western side than the eastern side of the delta plain. With the bulge out of the recent delta plain, the current shorelines (shorelines 7 and 7a) were shifted further towards the sea. In addition, nine sets of dune ridges are found in the eastern delta plain, whereas six sets of dune ridges are found in the western delta plain (Fig. 3.3). The second, fourth, and ninth sets of dune ridges do not exist in the western delta plain. However, all the dune ridges indicate the successive positions of retreating shorelines. The wide and extended Holocene tidal basin exists in the parallel position of the second set dune ridge on the western side.

3.3.3 *Geomorphology of Subarnarekha Delta*

Ten diverse geomorphological features have been discovered within a 12 km wide and 90 km lateral extension of the Subarnarekha basin's nearly symmetrical delta-plain (Fig. 3.4). In comparison to the straight course, three prominent river meanders extended the river course by about 10 km. At the swinging positions of the meandering course, the fluvial terrace has been formed and is dominated by the silt and clay material (Fig. 3.4) (Jana & Paul, 2022). Within this 12 km wide delta-plain, a series of beach ridges, dune ridges, barrier bars, and marine terraces have been formed under the different depositional environments controlled by the marine agents within an ancient lagoonal setting (Niyogi, 1968). The ancient beach has been converted into a marine terrace (sandy), which has been further modified into a dune ridge by the deposition of windblown sand (Paul, 2002). The beach ridges formed by the dominant wave actions (storms) with the deposition of coarser sand and marine shell fragments run parallel to present and ancient shorelines. The elevation of the ridges is controlled by the wave height corresponding to the wave energy to carry and deposit the materials. In most of the cases, the beach ridges are about 4–7 m elevated, and somewhere the older beach ridges are lowered down by the aeolian actions. In front of the estuary, these ridges are wider due to the effects of the high-energy wave action in the deeper water section, and they gradually narrow down when they form away from the estuary margins. The barrier bars are formed in the offshore region with sediment deposition under the dominance of longshore drift. The barrier bars are formed initially as submerged bars that remain underwater (as seen in the shallow sea region of the Subarnarekha mouth) (Fig. 3.4), then wave action acts on them when the bar becomes elevated and is only submerged by high tides (Jana et al., 2014). At the later stages of growth, the bars are subjected to aeolian action, with windblown sands being deposited on the bar surface. At the backside of the barrier bar, the lagoonal basins or tidal flats are formed under the backwater and tide-dominated marine environment with the deposition of finer materials (silt and clay).

The sand dunes or dune ridges are formed by the deposition of windblown sand from the beach sections. The dune elevation varies from 1–2 m to 15–18 m within the Subarnarekha delta-plain. The most prominent dune ridge (Contai–Baliapal dune ridge) is found at the northern (landward) extent of the Chenier landscape (Fig. 3.4). The shape, size, and extension of the present and ancient dune ridges indicate the shoreline configurations as well as the relative stability of the shorelines at certain positions. Most of the ancient beach ridges and some of the barrier bars have been entirely or partially converted into dune ridges. Therefore, in some places, the ridge collision or ridge bifurcation types of morphological features are found with the crenulated landward margins, regardless of whether the seaward margin is straight enough (Paul, 1996a). The beach ridges, barrier bars, and dune ridges are situated over the marine terraces, which are made up of sand, silt, or a mixture of both these materials. At the initial phase, this marine terrace remained a submerged coastal plain dominated by the marine and fluvio-marine environments. Then the

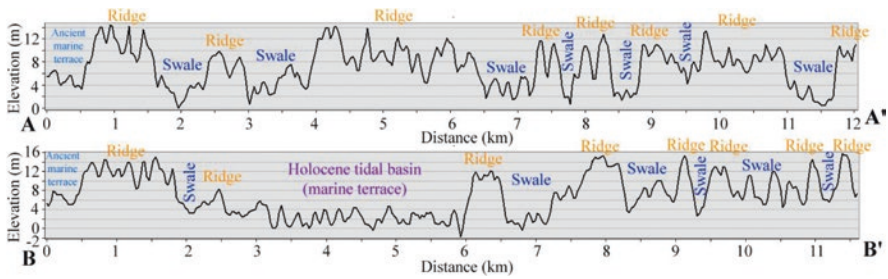


Fig. 3.5 Sequential dune ridge and swale landforms extracted by the cross-profiles

upliftment of the deltaplain (relative to the sea level) took place, and finally the marine terraces rose up in successive phases and appeared in their present form. The natural levees of fluvial deposits and irregular sandy patches of the marine deposits are also found over the marine terraces. The ancient beach that formed at the landward edge of the lagoonal settings is transformed into a marine terrace (sandy in nature), which remains neither on the dune ridge top nor at the edge of the lagoonal clays.

The fragmented natural levees represent the pattern of palaeo rivers and tidal channels over the deltaplain (Fig. 3.4). The natural levee was formed by the deposition of sand and silt-size sediments by the fluvial process beside the river or channel course. The river courses are filled up by sediments after the river flow is disconnected or dies from the main river, and the natural levees remain relatively elevated. The fluvial terraces remained on both sides of the Subarnarekha River (Fig. 3.4) in the avulsion position, composed of silt and clay materials. Both the cross-profiles (AA' and BB') provide ample evidence about the evolution scenario of the Subarnarekha deltaplain (Fig. 3.5). The AA' cross-profile is extracted across the eastern part of the deltaplain, whereas the BB' is extracted from the western side (Figs. 3.1 and 3.5). The profiles have been drawn from the landscape portion of the ancient marine terrace (landward margin) to the shorefront portion. Both cross-profiles show sequential ridge and swale topography (Fig. 3.5). However, the Holocene tidal basin as well as the marine terrace is dominated by the silt and clay types of materials within 3–6 km of the BB' cross-profile, whereas dune ridges are present in the same position as the AA' cross-profile (Fig. 3.5).

3.4 Conclusion

The Subarnarekha deltaplain's eight diverse landscapes and ten distinct geomorphological features formed and evolved over time under the distinct depositional environments controlled by the fluvial, marine, and fluvio-marine environments. The nine sets of Chenier dune ridges and swales were formed between 7000 and 50 YBP across the deltaplain. All these dune ridges are analogous to the existence of

progressive shorelines towards the sea. The second, fourth, and ninth sets of dune ridges are absent in the western side of the delta plain, as are the 5 and 5a shorelines, revealing the western delta plain bulge at a minimum rate due to the lower volume of sediment deposited in that side in comparison to the eastern side of the delta plain. The westward shifting of the Subarnarekha River near Chaumukh section was directed by the strong northeastern littoral drift, which again shifted the eastern side with the strengthening of the southwestern monsoon.

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